Annual Summary Document Template[1]

Simulări cu sistemul YaPT și predicții penrtu curgerea materiei nucleare în ciocniri nucleare relativiste la Experimentul CBM” (acronim YaPT-CBM) *(Simulations with YaPT system and predictions for nuclear matter flowing in relativistic nuclear collisions at CBM Experiment)*

Director de proiect
Prof.univ.dr. Alexandru JIPA

1. Cover Page (1 page)

- **Group list** (*physicists, staff, postdocs, students*);

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- **Specific scientific focus of group** (*state Physics of subfield of focus and group's role*)

One of the main objectives of the research of the nuclear collisions at relativistic energies is the study of nuclear matter phase diagram and locating of the critical point of the phase transition. The most important phase is represented by the quark-gluon plasma. Experiments at FAIR- GSI offers the possibility to perform experiments under common conditions (collision over a wide range of energies using the same detector system), but at lower temperatures and at higher baryon chemical potential, in comparison with experiments performed at other international laboratories. The predictions indicate, in this case, that a first-order phase transition can be obtained and the critical point is the point which connects the first-order phase transition to the region of the second order phase transition, continuous–type, in the small baryon chemical potential region. Exploring a wide range of collision energies allows us to access some areas of interest, in different representations of the phase diagram (e.g., the temperature and the chemical baryon potential diagram). The existence of a critical point could be revealed by the increase of fluctuations (C.Athanasiou et al - Phys.Rev.D 82 (2010) 074 008). Therefore, *the overall objective* of the project is *to associate different types of flow* of nuclear matter in the participant region with *different phases of nuclear matter* formed in collision. Taking into account the expected behavior near the critical point - increasing fluctuations - *an objective of interest is the fluctuation investigation by analyzing the ordinary and factorial moments associated with distributions of interest*, especially those of multiplicity, transverse momentum and rapidity. Other physical quantities of interest that can provide information are strangeness fluctuations, temperature, net charge and baryon

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number fluctuations. If fluctuations are related to the vicinity of the critical point, then one can see deviations from Gaussian – shape of the multiplicity distribution. It could be observed by event-by-event analysis and by a non-monotonic behavior of the associated higher order moments. Event-by-event analysis is superior to an inclusive analysis because it is more sensitive to changes in system state, including to the degree of achievement of the thermodynamic equilibrium, which allows the use of Tsallis statistics (J.Stat.Phys.52 (1988) 479) and analysis of the behavior of the non-extensivity parameter as a function of the available energy. The sensitivity of the event-by-event analysis determined *one of the most important objectives* of the present research project: *using global analysis to highlight different types of flow*. By constructing different tensors, using the Cartesian components of the momentum of the particles produced in the same event, we can make some connections with different types of flow, from radial to triangular, with specific phases of nuclear matter and correlation with limit states between phases, such as the cumulative production of particles. Also, we can make predictions for the shape and temporal evolution of the participant region. *For achieving the all the proposed objectives*, it is absolutely necessary a first step, namely *improvement of the YaPT simulation system performance* and *adding of new features*: parallel processing implementation for each of the requests made from the web interface and a prioritization system of the simulations, implementation of a new analysis modules in conjunction with the objectives of this project. *Another objective* is the improving knowledge related to the detector operation for such measurements.

- **Summary of accomplishments in the last year**

In the first stage of the contract – July-December 2014 – in agreement with objectives and schedule of the project – a few activities have been performed for the *developing of the package of the simulation codes included in the YaPT system*, as well as, for the *increasing of the handling of the simulation codes package.* A few *applications for the CBM Experiment* have been done. In this sense, to the three existing simulation codes (UrQMD, AMPT and GEANT), others have been included in the YaPT system, namely: PYTHIA and GiBUU. A first extension of the physical basis of the modelation has been done. The billiard ball model has been upgraded, taking into account some physical aspects specific to the relativistic nuclear collisions [1].

As a consequence of the accomplishment of a few specific activities for this stage of the project, namely: *utilization of the simulation codes package for detectors system from the CBM Experiment using the calculators cluster of the Research Center „Nuclear Matter in Extreme Conditions",* in connection with the *completed simulation codes package mentioned*, a large number of simulations has been done (over 200) including 2,5 TB storage memory.

Two papers have been published on the basis of the works presented at the *International Nuclear Physics Conference, Florence, Italy, 2-7.VI.2013,* works containing simulations with YaPT system [2,3].

Taking into account the necessity to have good agreement among simulation code predictions and the detection possibility, in confidence and accurate conditions, both experimental and statistical, the investigation of the observation possibilities of some interesting physical phenomena and processes begun [C1, C2].

2. Scientific accomplishments (max. 3 pages) – Results obtained in the last year

The scientific accomplishments were and will be related to the performances of the computer cluster. The cluster hpc.fizica.unibuc.ro was created to fulfill the need of high performance computing required by the Research Center „Nuclear Matter in Extreme Conditions". The cluster is based on CentOS operating system and Rocks Cluster System. This cluster is the fundamental stone used by the YAPT system, as it is the one used by YAPT to compute its tasks. It is composed of 10 Servers, 1 Frontend Server and 9 Computing nodes. The servers from this cluster are Super Micro twins and there are organized as it is presented in Table I.

The cluster is configured such that it can be integrated with any international GRID system. The computing power of the cluster fulfils the need of the local research teams, but for intensive use it will need an upgrade of the actual infrastructure. The YAPT system is configured on the Frontend and is accessible by the researchers and the students from any location. All the simulations requests are gathered by the PBS system on the frontend and distributed to the computing nodes. All the simulations are stored on a NFS share from the frontend. An example of storage for simulations with UrQMD code is shown in Table II.

Table I The servers from cluster and its performances

Server	***RAM***	***CPU's***	***Nr. Of CPU Cores***	***HDD***	***Computing nodes names***
Front End	2x16 GB	4xIntel® Xeon® Processor E5405 (12M Cache, 2.00 GHz, 1333 MHz FSB)	16	2x1 TB 2x320 GB	HPC.fizica.unibuc.ro Compute-0-0
Server 1	2x16 GB	4xIntel® Xeon® Processor E5405 (12M Cache, 2.00 GHz, 1333 MHz FSB)	16	4x320 GB	Compute-0-1 Compute-0-2
Server 2	2x8 GB	4xIntel® Xeon® Processor E5405 (12M Cache, 2.00 GHz, 1333 MHz FSB)	16	4x320 GB	Compute-0-3 Compute-0-4
Server 3	2x8 GB	4xIntel® Xeon® Processor E5405 (12M Cache, 2.00 GHz, 1333 MHz FSB)	16	4x320 GB	Compute 0-5 Compute-0-6
Server 4	2x8 GB	4xIntel® Xeon® Processor E5405 (12M Cache, 2.00 GHz, 1333 MHz FSB)	16	4x320 GB	Compute-0-7 Compute 0-8
5 Servers	112 GB	20 CPU	80 Cores	7.78 TB	10 Servers

Table II An exemple of storage in cluster for simulations with UrQMD code

	Energy [GeV/A]	Number of events	Average number of collisions	Average number of final particles	Real time	User time	F14 file size [GB]
plb	5	10000	496.5975	466.0457	178m11.671s	172m8.005s	36
plb	10	10000	581.0693	525.1036	239m45.097s	224m53.872s	38
plb	20	10000	588.5187	599.7973	304m57.432s	288m30.252s	42
plb	25	10000	594.2013	628.2623	332m19.297s	315m25.500s	44
plb	30	10000	597.5657	652.9554	358m36.046s	341m49.929s	45
Plb	40	10000	596.0892	691.6612	504m2.095s	496m12.703s	48

As the number of existing simulations is growing rapidly under the intensive use of the YaPT system, we have been investigating solutions to extend the storage space available to the user simulations. Spare disk units have been mounted into the system via the widely used NFS (Network File System) and used to archive old simulations. The problem to deal with here was related to the intense use of the NFS units as users are accessing data through the web interface, and the use of the simulators themselves to write data. As the simulations are being performed, only the most recent ones are subject to such heavy traffic, and consequently the other simulations are only sparsely accessed by no more than 1-2 users at the same time. Since the physical space is always limited, we performed a different optimization for the system.

The simulations for all the codes are having a common output, namely writing into the same ASCII format known as OSC1997A format. This feature allowed us to use the same ROOT code to perform the transition to ROOT trees, well suited for end user analyses. As soon as the tree is generated, the input ASCII results may be archived, or even deleted, as long as the input generator file is kept for further reference. The implementation of this solution resulted in a factor 4 decrease of the simulations' size. The output simulations' size would be finally dealt with when the foreseen NAS server would be up and running, possible by the next year. Taking into account our major objectives for next period, we will consider upgrade of the hardware, as follows: (i) a new Gigabit dedicated switch for the cluster; (ii) dedicate storage system bigger Hard Drives; (iii) upgrade the RAM memory used by the server, and include new servers in the cluster; (iv) a dedicate firewall to protect the system

One important results of the first period was the *implementation of a new code*. The most interesting for the investigation of the collective behavior of the nuclear matter is PYTHIA code. For the YaPT system, we have implemented the PYTHIA8 package. PYTHIA8 is the C++ development of the old Fortran code PYTHIA6 [http://home.thep.lu.se/~torbjorn/Pythia.html]. PYTHIA8 and its tunes are widely used in the worldwide heavy ion collisions community (at CERN, GSI, BNL), both to model the reference elementary interactions which serve as basis of comparisons with the heavier systems, but also to study the perturbative QCD regime (pQCD) via jet observables, like parton distributions, initial and final state parton showers, multiple interactions and fragmentation and decays of the interacting partons. It worth's to notice that PYTHIA6 is still heavily used, as the results obtained with the 2 distributions might differ, at least until advanced investigations. Therefore, it is foreseen to implement also the PYTHIA6 into the system. PYTHIA6 does not evolve anymore, whereas the PYTHIA8 is still under heavily development. PYTHIA8 has different versions, and might use its internal wrapper to ROOT to write the simulations' output into ROOT files, and even more, into ROOT internal structures, like ROOT trees. For the reasons explained below, we have chosen the 8180 version. The advanced use of the PYTHIA8 simulation engine would follow the direct use of the program and its ROOT plugin. For first sight results with PYTHIA8, as it is intended for the full YaPT system (teaching purpose, easiness of use, etc) the 2nd approach is well suited, namely the PYTHIA implementation into ROOT, performed by Andreas Morsch (GSI). ROOT code is calling PYTHIA(8) library via a wrapper and uses it to generate the particles via the interactions, taking in the end the control to output particles in ROOT tree. This ROOT wrapper is having basic functionalities (like setting/reading PYTHIA arguments like physics processes, energy), but for other advanced purposes, either the plugin could be further developed, either the direct use of PYTHIA8 has to be done. The PYTHIA 8201 version has been tested, but the ROOT plug-in was found not to be working, as the PYTHIA8 interface has changed, and some development has to be done on the ROOT wrapped side.

As soon as the particles ROOT tree is generated, the analysis continues as the standard procedure, using the ROOT macro to generate particle distributions for physical observables like transverse momentum, rapidity/pseudo-rapidity, particle ratios suited for statistical interpretations. Such observables are generated for each type of hadrons (baryons and mesons).

PYTHIA8 is widely known for the great number of input parameters that might be changed by the user. For the moment, only a limited number of parameters are available through the main interface (number of events, energy in the chosen frame system that can be either laboratory for fixed target collisions, either center of mass system, for using at collider accelerators, soft QCD physics selections, as single and double diffraction switches). This set of available parameters to change via the YaPT interface is considered adequate for this time, but it will be extended in the future.

In parallel to the core YaPT system extensions, an important development has been done on the end user functionalities side, namely providing more analysis tools for a give simulation. Of big interest is the analysis of multiplicity factorial moments. This method is being used by our group to study collisions at RHIC and FAIR energies, and has been one of the original reasons that stayed at the base of YaPT principles – to have a friendly interface to a powerful cluster server, in order to simulate large data sets for various collisions. A special module performing multiplicity moments' analysis has been written for YaPT, and it will be available shortly. A YaPT "analysis module" has to fulfill certain requirements, namely: (i) it has to be independent of energy and colliding system, meaning that it has to find by itself the range limits to be used for the distributions – like p_T range, rapidity range, bin size, etc; (ii) every distribution has to be exported in the png format, in order to be displayed on the YaPT summary page; (iii) it must deal with the normalization issues, like event normalization, rapidity range and bin sizes, in order to be able to compare different energies/systems; (iv) robust dependencies integration, to be able to be compiled by ACLIC, as the speed of iterating large dataset has to be large. Thus, with this module, we will have 2 complete sets of different observables that the user has at hand, and the system is doing one step ahead in providing the users with the tool of uploading a custom macro to be executed on a dataset. For the moment, the multiplicity moments' tool is under development, and it will be available in YaPT shortly.

One of the major tasks in our *understanding of the QCD phase diagram* is *locating the QCD critical point (CP)*, connecting the first-order boundary separating the hadronic from the partonic matter at high density with the cross-over boundary at low density. Experimentally, we can probe this phase diagram with nuclear collisions of heavy nuclei at different energies where the matter is heated and compressed. The system created in such collisions follows different trajectories on the temperature (T) and baryon chemical potential (μ_B) coordinates during its time evolution. The characteristic signature of the existence of a CP is an increase of fluctuations that can be evidenced by studying the event-by-event moments of various observables in heavy-ion collisions, like charge/baryon number /strangeness.

Therefore, higher moments (skewness and kurtosis) of multiplicity distributions are proposed to provide one of the most sensitive probes towards the search for the CP because are conjectured to reflect the large fluctuations associated with the hadron-quark phase transition. For example, *a sign change in the skewness (S) or kurtosis (K) may be an indication that the system crossed the phase boundary*. This is one of our objectives, too.

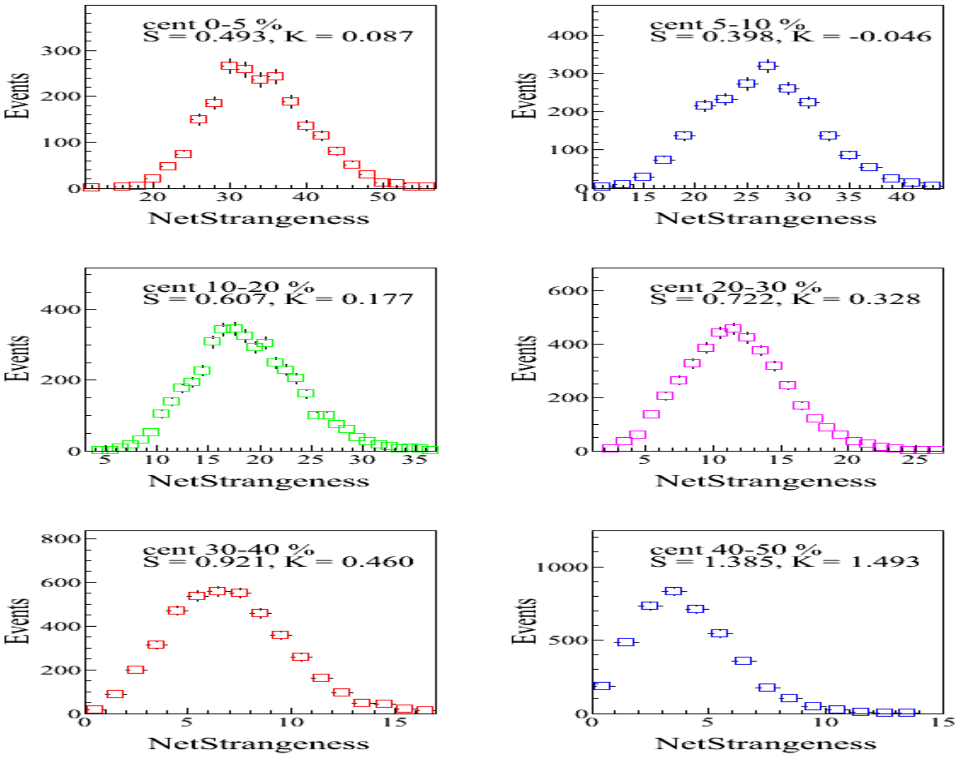

Fig.1.The centrality dependence of the net-kaon multiplicity distributions using UrQMD code for Au+Au collisions at p_{lab} = 25 GeV/c

Fig.1 presents primary multiplicity moments distributions that are further compiled to produce broader figures showing their evolution with the beam energy and number of participants (reflecting the system size). The two higher order moments (S and K) which describe the shape of the net-kaons distributions in Au+Au collisions at various collision energies are plotted as a function of the number of participants, N_{part} (Fig.2).

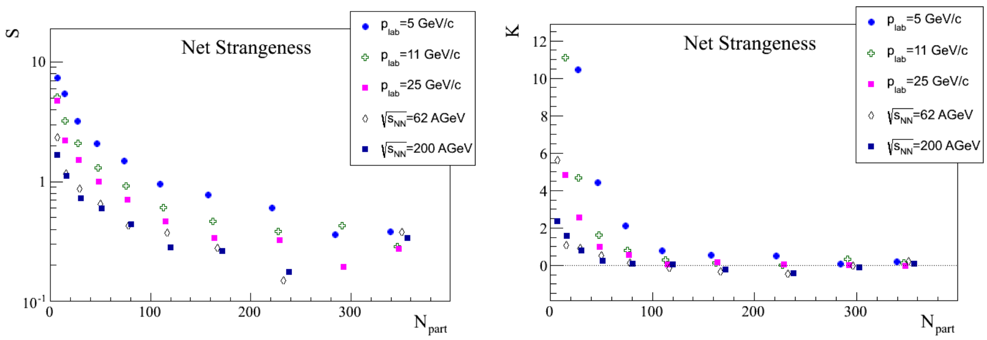

Fig.2. The centrality dependence of the net-kaon skewness (left panel) and kurtosis (right panel) in Au+Au collisions at different energies simulated using UrQMD code

For all studied energies, the skewness is positive and decreases as the number of participants increases. For the same collision centrality (same N_{part}) skewness values decrease as the beam energy. These results are obtained using UrQMD code, which does not contain any QGP phase transition, and, therefore, may be used as basis for the study of real collisions that will take place at the FAIR facility.

Other interesting work direction in this period was the developing of the own CMBE code based on the nuclear billiard model. The code is written in C#. Using the chaos theory, as well as billiard model, the bi-particles interactions for n-body system have been introduced. A Runge-Kutta second order algorithm for solving Newton equations', in relativistic form, is used. At the bi-particles interactions a decays module has been introduced. Combining the two modules complex interactions can be considered. The list of the specific parameters needed must be specified as an input parameter, using a XML file. For analyzing the dependence on the initial conditions („butterfly effect" – specific to the deterministic chaos), a new module has been introduced. It is possible to take into account very small perturbations, over the limits imposed by the compilations systems. This new module was used for analyzing nucleus-nucleus collisions at energies comparable with SIS-100 energies. The developments from the last period permitted the increase of the energies up to the maximum RHIC-BNL energy, for large combinations of colliding nuclei. Some improvements have been obtained in the fit to the existing experimental results if the particle lifetime in laboratory system is introduced.

All these scientific accomplishments are included in the published and communicated works.

3. Group members (*table*)

- List each member, his/her role in project and the Full Time Equivalent (FTE) % time in project. The FTE formula to be used is: FTE = Total number of worked hours in the last year/1020 hours[2];

- List of PhD/Master students and current position/job in the institution.
  1. Nicolae George ȚUȚURAȘ - PhD students
  2. Elena GIUBEGA – PhD student
  3. Alexandru ENE – Master student
  4. Horea BRÂNZAȘ - Master student

4. Deliverables in the last year related to the project

- List of papers (journal or conference proceeding);
- List of talks of group members (title, conference or meeting, date);
- Other deliverables (patents, books etc.).

List of papers (journal or conference proceedings) in 1st semester (July – December 2014)
[1]. CMBE v05 Implementation of a toy-model for chaos analysis of relativistic nuclear collisions at the present BNL energies – I.V.Grossu, D.Felea, Al.Jipa et al – Computer Physics Communications 1859(11)(2014)3059-3061 [2]. Study of the multiplicity distributions in relativistic nucleus - nucleus collisions using the multiplicity distribution moments method – C.Ristea, Al.Jipa, Oana Ristea et al - EPJ Web of Conferences 66(2014)04024 [3]. Study of the particle transverse momentum spectra in relativistic heavy ion collisions using the Tsallis statistics – Oana Ristea, Al.Jipa, C.Ristea et al - EPJ Web of Conferences 66(2014)04025
List of talks of group members (title, conference or meeting, date)
[C1]. On the performances of YaPT (Yet another High Energy Physics Tool) – Al.Jipa, M.Călin et al – International Conference on High Energy Physics, Valencia, Spania, 2-9.VII.2014 [C2]. Simulations with YaPT system for nucleus-nucleus collisions FAIR-GSI energies Quark Matter 2014 – Al.Jipa et al – XXIV International Conference on Ultrarelativistic Nucleus-Nucleus Collisions, May 19-24, 2014, Darmstadt, Germany

5. Further group activities (max. 1 page)

- Collaborations

- with *Institute of Space Science Bucharest-Măgurele* and *National Institute for Physics and Nuclear Engineering „Horia Hulubei" București-Măgurele* for development of the YaPT system, both in hardware and software directions
- with *Civilian Maritime University of Constantza* for studies on nuclear matter jets in nucleus-nucleus collisions, identification of the reaction plane, correlations between cumulative production of the charged particles and flow processes, nuclear matter jets, mainly

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[2] 1020 hours = 170 average monthly hours x 6 months

- Education

- the YaPT system was used at the practical classes associated to the course of the *High Energy Nuclear and Particle Physics Phenomenology* – Master studies in the field *Physics of atom, nucleus, elementary particles, Astrophysics and applications* - second study year, first semester of the academic year 2014-2015

- Outreach

- problems related to the nucleus-nucleus collisions have been presented at the following young people meetings:

(i) Pentagon of the major Romanian Physics faculties, Bucharest-Măgurele, July, 29th, 2014 (Prof.univ.dr. Alexandru JIPA),

(ii) 90th Anniversary of the Military High School „Ștefan cel Mare" Câmpulung Modlovenesc, 21.XI.2014 (Prof.univ.dr. Alexandru JIPA)

6. Financial Report for the last year (see the Annex)

7. Research plan and goals for the next year (max. 1 page)

In the first six month of the project the main objectives were related to the development and the use of the simulation software package included in the YaPT system, as well as some applications for the CBM Experiment have bee done. The new codes included in the YaPT system (PYTHIA, GiBUU), together with the existing ones (UrQMD, AMPT and GEANT) include many useful elements for the description of the collective behavior of the high excited and extreme dense nuclear matter formed in nucleus-nucleus collisions at SIS-100 and SIS-300 energies. The use of specific software package for the detection systems of the CBM experiment in connection with the software package developed by the collaboration permitted some estimation on the possibility of observation of some processes and phenomena of interest.

For the next six months, simulations with different codes of symmetric and asymmetric collisions at energies available at the SIS-100 and SIS-300 will be done. With the simulation results a detailed analysis of the flow processes will be performed. We will begin with the competition between the flow processes and the partial stopping, using methods based on correlations and fluctuations in multiplicity distributions in agreement with the previously proposed methods (Al. Jipa et al - JPG: Nucl.Part.Phys.22(1996)231, C.Ristea et al. - EPJ Web of Conferences 66(2014)04024). We will continue to analyze the flow processes using the global analysis, especially the flow tensor and the "thrust" tensor. We will use simulation data for extraction of the values for the flow angle, flow factor, etc. On the basis of the flow factor, we will make connections with elliptic flow, as well as with other types of flow. Some analogies based on comparisons between the simulated data and experimental results from other experiments of interest already developed will be done, too.

After these studies, the activity will be focused on the study of the nuclear jets formation and the connections with the cumulative particle production. The results obtained at energies of the order of GeV per nucleon - (C.Beşliu et al - EPJA1(1998)65-75), in asymmetric and symmetric collisions between two light nuclei will be used as a basis for ordering the equivalence classes, taking into account the cumulative particle production, as an expression of the phase transition regime envisaged for the specific energies at FAIR- GSI. The analysis of these collisions in different centrality classes, taking into account the fluctuations of physical quantities of interest, could lead to the idea that the development of the phase transitions may or may not be connected to specific types of nuclear jets. Based on the specific results, then we will use the blast wave model to describe the behavior of hot and dense nuclear matter formed in the investigated collisions. We will estimate the chemical and thermal freeze-out parameters and study the centrality and rapidity dependency of these parameters. It will make the analysis of the signals for various phase transitions in connection with possible correlations. It will also investigate the instabilities in nuclear matter formed in collision, in connection with the centrality and rapidity.

We consider that for the complete accomplishment of the proposed objective of the project a few collaborations must be opened, namely:

- with *Institute of Space Science Bucharest-Măgurele* and *National Institute for Physics and Nuclear Engineering „Horia Hulubei" București-Măgurele* for development of the YaPT system, both in hardware and software directions
- with *Civilian Maritime University of Constantza* for studies on nuclear matter jets in nucleus-nucleus collisions, identification of the reaction plane, correlations between cumulative production of the charged particles and flow processes, nuclear matter jets, mainly.

Annex

Financial Report
according to the regulations from H.G. 134/2011

			lei
Type of expenditures		**Year**	
		Value	
		Planned	**Realized**
1	**PERSONNEL EXPENDITURES**, from which:	**50195**	**50195**
	1.1. wages and similar income, according to the law	40963	40963
	1.2. contributions related to salaries and assimilated incomes	9232	9232
2	**LOGISTICS EXPENDITURES**, from which:	**0**	**0**
	2.1. capital expenditures	0	0
	2.2. stocks expenditures	0	0
	2.3. expenditures on services performed by third parties, including:	0	0
	....	0	0
3	**TRAVEL EXPENDITURES**	**0**	**0**
4	**INDIRECT EXPENDITURES – (OVERHEADS 25% from Direct Costs) ***	**12547**	**12547**
TOTAL EXPENDITURES *(1+2+3+4)*		**62742**	**62742**

* Specify the rate (%) and key of distribution (excluding capital expenditures).

To be filled in for:
- the project leader;
- for each of the parteners (if any);
- for the whole project.